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SPECIAL INCLINOMETERS
AND
TURN INDICATORS
FOR
AERIAL NAVIGATION

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The following publication, entitled "Special Inclinometers and Turn Indicators for Aerial Navigation," is published for the information and guidance of all concerned.

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SPECIAL INCLINOMETERS AND INDICATORS.

In this pamphlet will be described some of the best forms of inclinometers and turn indicators. Some instrument of the sort is much needed on airplanes used for reconnaissance work and bombing.

1. Inclinometers.

The function of inclinometers is stated in the pamphlet "Inclinometers for Aerial Navigation," where it is also pointed out that the bubble inclinometers in use have a limited value, because affected by accelerations of the airplane. Now, for certain purposes it is highly desirable to have an inclinometer which will be independent of the motions of the ship and at all times furnish a vertical line or horizontal plane of reference. The uses of such an inclinometer are as follows: (1) In bombing and mapping by photography it will furnish a reference to the pilot for holding the airplane level; (2) in cloud flying it will enable the pilot to keep the ship right side up and, to a limited degree, on a straight course; (3) in navigation where the use of a sextant is necessary it will furnish a horizon.

While no such inclinometers have been adopted by the Air Service, a vast amount of experimental work has been done and some reference should be made of the more promising instruments. All of these have made some use of the gyroscopic principle.

The simplest gyro inclinometer is the French "Toupie Garnier." This is shown in Figure I. The rotor C has a pivot on the lower side and a pointer on the top. The pivot rests in a jewel cup, and the center of gravity is below the point of support. The case in which the rotor is mounted is air-tight except for two small holes which direct air jets on the rotor, and a tube *a* which is connected to a double Venturi. Air is drawn *out* by the action of the Venturi through *a*, and *in* through the two small holes so that jets of air are directed on the rotor and it is set to spinning. The glass cover is a cap of a spherical shell and has a scale, so that the inclination of the pointer is readily shown.

When the axis of spin is displaced from the vertical a torque is brought into play which produces a precession, which is opposed by the friction of the pivot. Thus the pendulosity in conjunction with the unavoidable friction serves to bring the spin axis to a vertical position. However, an error is produced by a horizontal acceleration of any sort, so that on a turn a precession at right angles to the radius of turn is set up which seriously displaces the gyro from the

vertical, and it gets into circular oscillations which persist for some time after the turn.

In the French instrument a further error is introduced when the axis of spin is inclined to the axis of the case, due to the fact that the torque of the jets is no longer normal to the axis of spin. It was found that a rotor may be constructed without "buckets," which may be driven just as satisfactorily by skin friction, and with a broad enough spherical shell so that the air jets will not overshoot. This is some improvement over the original Toupie Garnier.

However, at the best this instrument is not accurate enough for bombing and photography and is not as reliable for cloud flying as the turn indicator to be described later.

The Titterington inclinometer manufactured by the Sperry Gyroscope Co. is similar in principle to the Toupie Garnier. It is a long period gyro pendulum in which the rotor is the armature of a three-phase alternating current motor, the alternating current being supplied by a small fan generator carried on the airplane. The circular oscillations originating on turns are damped out by means of an air blast pumped by the rotor and directed by small vanes hung on an ordinary gravity pendulum. The instrument is fairly satisfactory when in good adjustment, but does not seem rugged enough for airplane use.

A stabilizer developed by Dr. A. W. Duff and Lieut. W. A. Hyde for carrying a bomb sight, and very satisfactory for this purpose, may be used as an inclinometer. This is shown in Figure II. This is a short period gravity pendulum in which the oscillations are damped by air dashpots, the pistons of which are fastened to a neutral gyrostat. The pendulum part is mounted on gimbals so as to be free to move about two horizontal axes *aa* and *bb* at right angles to each other. The gyro is of the Sperry alternating current motor type. This is mounted at the top of the pendulum with the spin axis vertical, and on gimbals so there are two horizontal axes of rotation, $a'a'$ and $b'b'$, parallel to *aa* and *bb*, respectively. Four dashpots *C* are fastened to the pendulum and the pistons to the case of the gyro by hinged joint. The axis of spinning gyro tends to remain fixed in space and furnishes a more or less stationary position for the dashpot pistons.

This gyro pendulum furnishes a very good stabilizer against short-period oscillations. But on long turns the steady torque applied through the dashpot gives a precession to the gyro from which it is slow to recover.

To be used as an inclinometer the bomb-sight parts would be replaced by a bar and weight to serve as a pendulum and with a pointer attached to indicate on a scale fastened to the airplane the position of the airplane with reference to the pendulum, which will be to a greater or less degree stabilized in space.

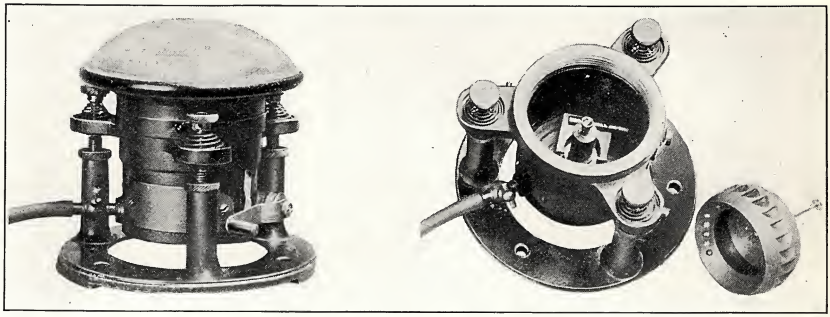

FIG. I.—TOUPIE GARNIER.

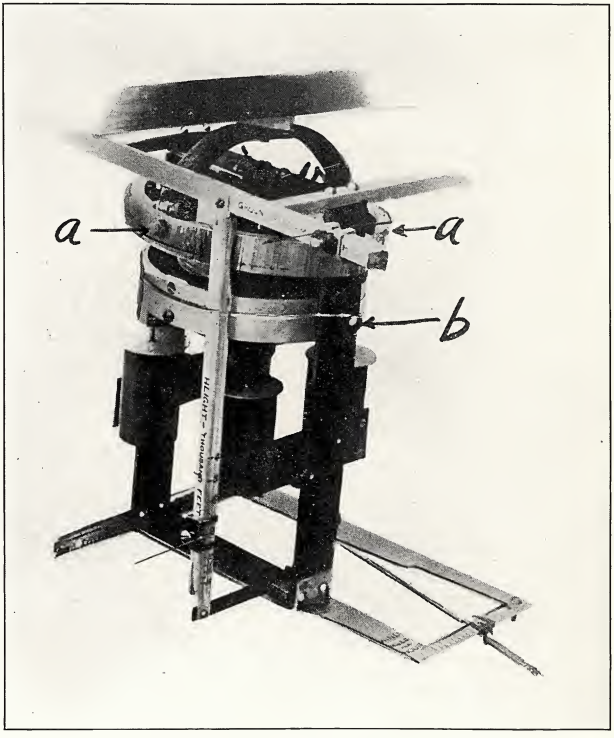

FIG. II.—DUFF-HYDE STABILIZER.

2. Turn Indicators.

The purpose of a turn indicator is somewhat analogous to that of an inclinometer, but more limited. As its name indicates, it is intended to show when a turn is being made.

As is pointed out in the pamphlet "Compasses for Aerial Navigation," a compass can not be trusted to show the process of a turn, especially on northerly courses. And since in flying in clouds or fogs, where there is no horizon or fixed object to guide the pilot, he can not know whether or not a gradual properly banked turn is being made, some additional instrument is necessary. The turn indicator furnishes all the additional information necessary, which is not furnished by the standard navigating instruments and through the senses of the pilot. It has been the experience of pilots who have used turn indicators in cloud flying that they are enabled to hold to straight courses, to turn off the old course to a new, and at all times to keep the airplane on level keel, which is quite opposite to the ordinary experience in cloud flying. A turn indicator that is reliable is a much needed instrument on bombing airplanes, and all airplanes, military or otherwise, which are used for long flights that must take place in all kinds of weather. The need of the instrument will increase as aircraft of long-range activities are developed.

Two types of successful turn indicators have been developed, the "static head" and "gyrostatic."

The former turn indicator has been used considerably by the British. From an indicator on the instrument board two lines of tubing of about one-fourth inch inside diameter run out toward the wing tips, one on the right and one on the left. The outer end of each tube ends in a "static head" similar to the static head of the R. A. F. Pitot tube, Mark IV–A. The forward end of this is closed by a bullet nose and there are a number of fine holes drilled through the side of the tube about 2 inches back of the nose.

Now, on a turn the centrifugal force acting on the air in the tubing on the outer wing is greater than the centrifugal force on the air in the tubing on the inner wing. Consequently more air is forced out through the static head on the outer wing and the pressure in the tubing on that side is less than the pressure on the inner, and this differential pressure causes the pointer on the indicator to move.

The indicator used is the Ogilvie balloon air-speed indicator, with a specially marked dial, which is capable of showing a very small pressure difference. It was found that the static heads must be mounted exactly parallel to each other and parallel to the line of flight in order to operate correctly. It is better to have the heads mounted on swivels with vanes so that automatically they take the direction of line of flight. When mounted on the outer struts this

indicator shows a side slip in a straight line as a turn in the direction of the slip. This error is removed when the static heads are mounted 2 feet above and 1 foot in advance of the upper wing. This is not a practical place of mounting, but this difficulty is of no consequence if known and understood, for the pilot can always distinguish a side slip from a turn by the side wind. This type of turn indicator will detect a turn at the rate of 2° per minute.

The gyrostatic turn indicator is a much simpler and more rugged type. It was developed by the Science and Research Department, and a similar instrument is being manufactured by the Sperry Gyroscope Co. This is illustrated in Figure III. The mechanism of the indicator is shown at B, which is inclosed in the case C. The gyro *a* is mounted on a horizontal axis in a gimbal *b*, which in turn is mounted on the frame. The pointer is mounted on the shaft *e* of the gimbal. The axis of spin is athwartship and the direction of spin such that upper rim moves toward the nose of the airplane. The axis of the gimbal *b* is parallel to the longitudinal axis of the airplane. The gyro is driven by air jets from the nozzles *d*. The case is airtight except for an outlet tube at the back, which is connected to the double Venturi A, which is mounted in the slip stream. As the air is drawn out of the case new air is forced in by atmospheric pressure through the inlet tubes *c* from which the nozzles open.

The hairspring *f* tends to keep the axis of spin horizontal. If the ship turns to the right a torque is exerted which turns the right end of the spin axis *up*. This torque is opposed by the hairspring, and as soon as the turning of the ship stops the action of the hairspring brings the gyro back to the zero position. When the turn is to the left the spin axis is tipped in the opposite direction. The torque acting on the spin axis is proportional to the rate of turn of the airplane, whether the turn is properly banked or skidded, so the instrument shows both properly banked turns and skidded turns. Since the tipping of the spin axis of the gyro is opposite to the bank of the ship on a turn, the instrument is very sensitive. If the airplane is banked over without turn, as in a side slip, the indicator is not affected. However, since the ship is generally turned slightly on going into a side slip the turn indicator at first shows a turn and then comes to a zero position as the ship comes to a straight line side slip.

This turn indicator has been thoroughly tested first by flights in clear weather and then by flights in clouds. It is found to be reliable and satisfactory in every particular.

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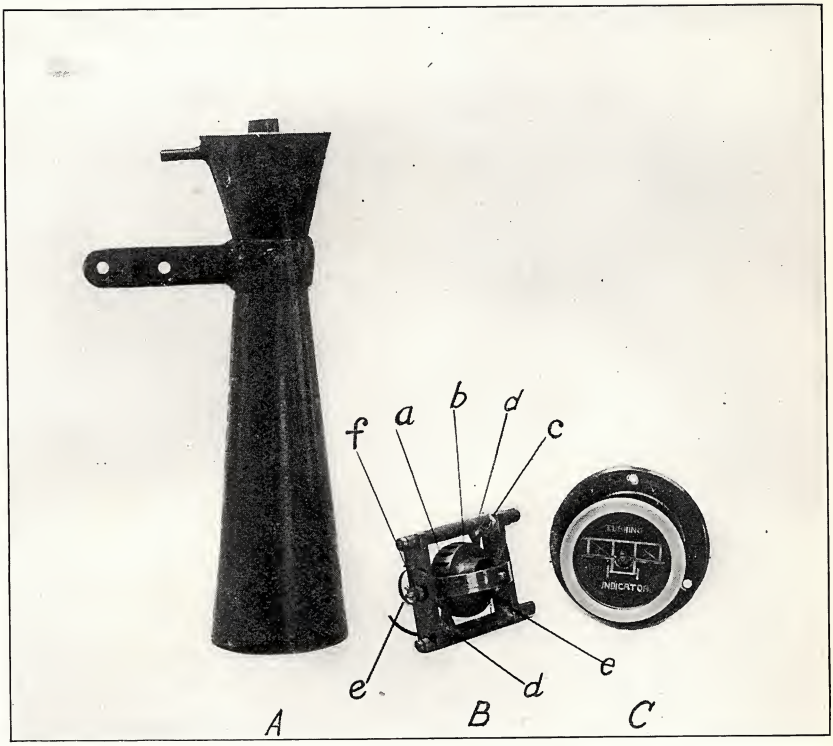

FIG. III.—GYRO TURN INDICATOR.